

Thermal Characterization of Adhesive

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ABSTRACT

The current Space Shuttle Reusable Solid Rocket Motor (RSRM) nozzle adhesive bond system is being replaced due to obsolescence. Down-selection and performance testing of the structural adhesives resulted in the selection of two candidate replacement adhesives, Resin Technology Group's Tiga 321 and 3M's EC2615XLW. This paper describes rocket motor testing of these two adhesives. Four forty-pound charge motors were fabricated in configurations that would allow side by side comparison testing of the candidate replacement adhesives and the current RSRM adhesives. The motors provided an environment where the thermal performance of adhesives in flame surface bondlines was compared. Results of the FPC testing show that 1) The phenolic char depths on radial bond lines is approximately the same and vary depending on the position in the blast tube regardless of which adhesive was used. 2) The adhesive char depth of the candidate replacement adhesives is less than the char depth of the current adhesives. 3) The heat-affected depth of the candidate replacement adhesives is less than the heat-affected depth of the current adhesives. 4) The ablation rates for both replacement adhesives are slower than that of the current adhesives.

KEY WORDS: ADHESIVE, THERMAL, AND CHARACTERIZATION

1. INTRODUCTION

Replacing the RSRM nozzle structural adhesive requires that all aspects of adhesive testing be performed and the replacement material be fully characterized. The intent of this testing was to obtain characteristics on thermal performance of adhesives in nozzle flame surface bondlines. This testing was conducted using Forty Pound Charge (FPC) motors configured in a manner that would allow side by side comparison testing of the current and replacement candidate adhesives in flame surface radial bond lines. This testing was used to obtain surface char and erosion behavior comparisons that were used to assist in the final selection of the primary replacement adhesive.

This testing evaluated two candidate replacement adhesives and the two current adhesives. Dexter Hysol EA-913 and EA-946 are the current RSRM adhesives. The replacement candidate adhesives are Minnesota Mining and Manufacturing's (3M) EC2615XLW and Resin Technology Group's (RTGs) Tiga 321.

2. TEST

Adhesive performance testing was conducted using four forty-pound charge motors. The FPC consists of a propellant case and nozzle. The nozzle consists of a housing, convergent cone; blast tube, throat and exit cone See Figure 1.

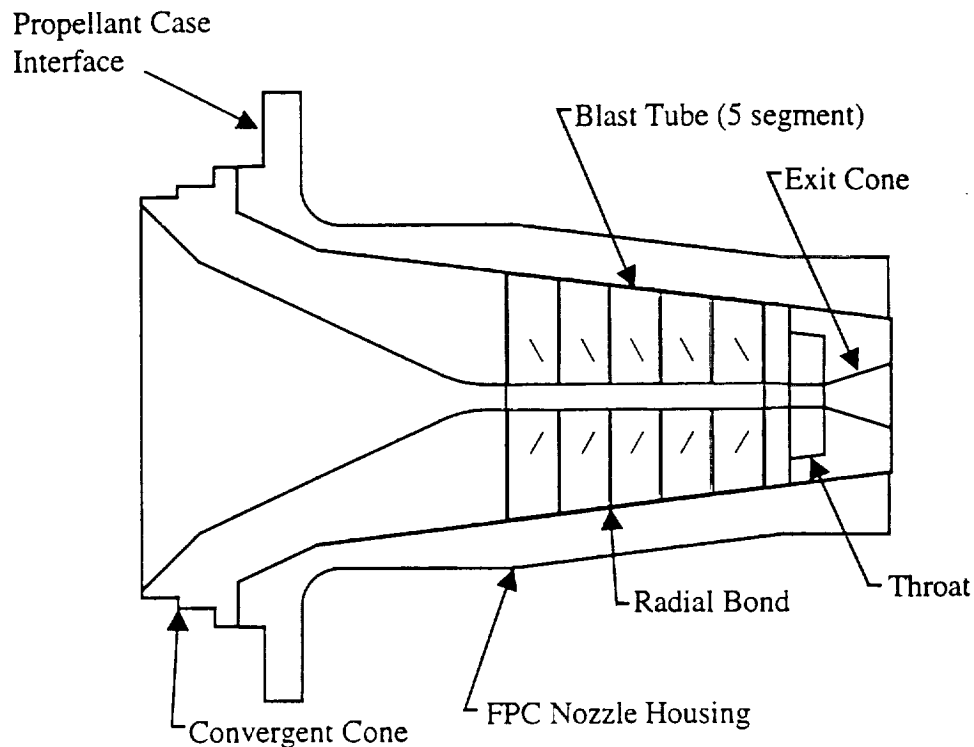


Figure 1: FPC Nozzle

The FPC configuration was designed primarily as a test bed for performance testing of nozzle ablative materials. For this test the blast tube section of the nozzle was changed to have five Carbon Cloth Phenolic (CCP) test rings instead of the usual two. This resulted in three additional radial bondlines (total of four) "sandwiched" between Carbon Cloth Phenolic (CCP) test rings. The blast tube was cut longitudinally such that the radial bondlines in one 180-degree half (pack) used current RSRM adhesives, while those of the other half (pack) used the proposed adhesives.

Each replacement candidate adhesive was tested eight times. Two times each at four locations. This placement was designed so that each candidate adhesive could be compared to each current adhesive at each station in the blast tube see Table 1 and Figure 2. This adhesive placement plan was prepared assuming that the same axial station in the nozzle would have the same flow velocities, pressures and temperature.

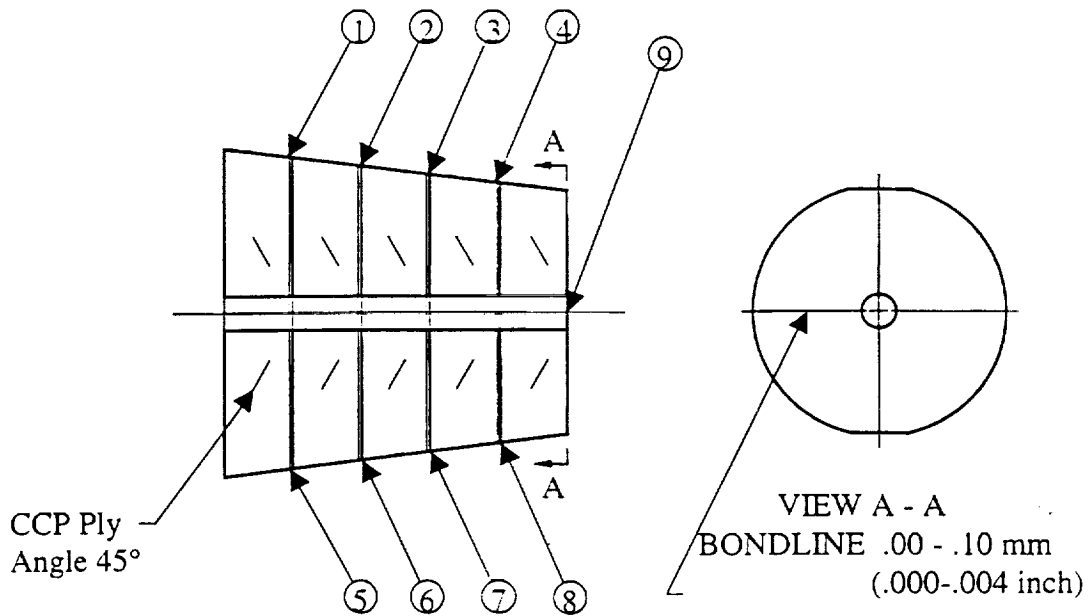


Figure 2: FPC Blast Tube Configuration

Test	Bond Location								
	1	2	3	4	5	6	7	8	9
1	EA-913	EA-913	EA-913	EA-913	3M	3M	RTG	RTG	EA-913
2	EA-946	EA-946	EA-946	EA-946	3M	3M	RTG	RTG	EA-913
3	EA-913	EA-913	EA-913	EA-913	RTG	RTG	3M	3M	EA-913
4	EA-946	EA-946	EA-946	EA-946	RTG	RTG	3M	3M	EA-913

Table 1: FPC Char Motor Material Layout for Two Replacement Candidates

All radial bondlines were approximately 1.0 mm (.040 inch) thick with the axial bondline being .001-.100mm (.000 - .004 inch). Thermocouples were placed in the radial bond lines starting 2.54mm (.100 inch) in from the flame surface and every 5.08mm (.200 inch) increment out toward the housing bond surface see Figure 3.

The thermocouples were intended to provide information on thermal gradients through the bondlines for current and replacement candidate adhesives. Placement of the

thermocouples was such that two in each bondline were expected to be destroyed during testing to obtain an ablation rate and two would remain through heat soak.

Key FPC char motor operating parameters are as follows:

Propellant	Shuttle STW5-3343 (lab designation TP-H1148)
Motor Burn Time	32 ± 2 seconds
Test Orientation	Vertical
Average Pressure	$4.826 \pm .345$ MPa (700 ± 50 psi)

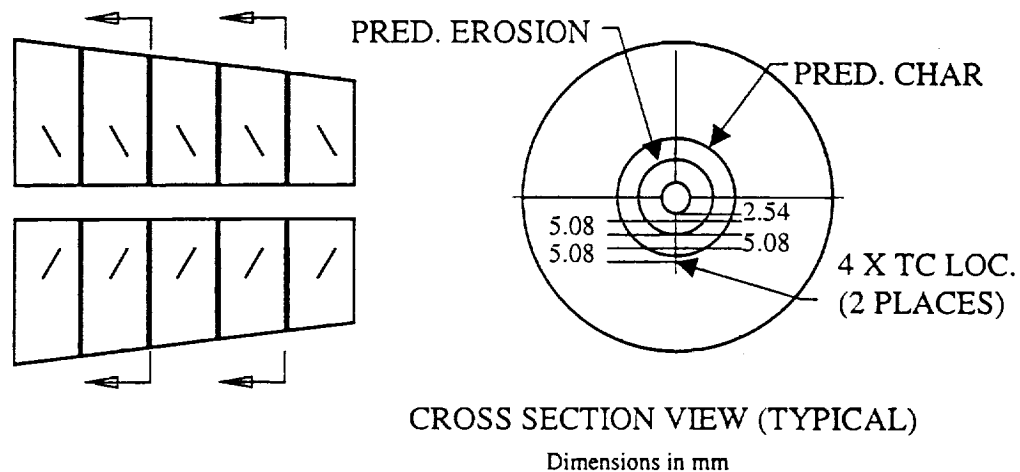


Figure 3: FPC Blast Tube Thermocouple Configuration

3. EXPERIMENTAL AND ANALYTICAL PROCEDURES

To build this test motor that would allow this side by side comparison testing a unique blast tube had to be manufactured. To start five conical blast tube phenolics approximately 25mm (1 inch) thick were built. The phenolics were stacked and aligned using a 12.7mm (.5 inch) diameter alignment tool placed inside the blast tube. Two flat areas were machined on the phenolic outside diameters, the length of the blast tube. They were aligned 180° apart to provide an instrumentation wiring path on each side of the blast tube. The individual phenolics were then sectioned into 180° halves. The appropriate section halves were instrumented as identified in Table 2 and were bonded per schedule in Table 1. A 12.7mm (.5 inch) diameter alignment rod was use to align the center bores of the blast tube sections while the assembly was being assembled and clamped together. This procedure produced a 180° pack. Two bonded packs were then bonded to form the blast tube assembly.

Before the motors were fired the bondlines were inspected and prefire measurements were taken. At the testing facility the propellant case was mounted into the test fixture in

the vertical position. The nozzle assembly was bolted to the propellant case and the instrumentation was connected. The instrumentation monitoring was started and the FPCs were fired. After cooling the assemblies were removed and disassembled. Photographs were taken (see figure 4) and measurements of remaining bondline adhesive were recorded (see Table 3).

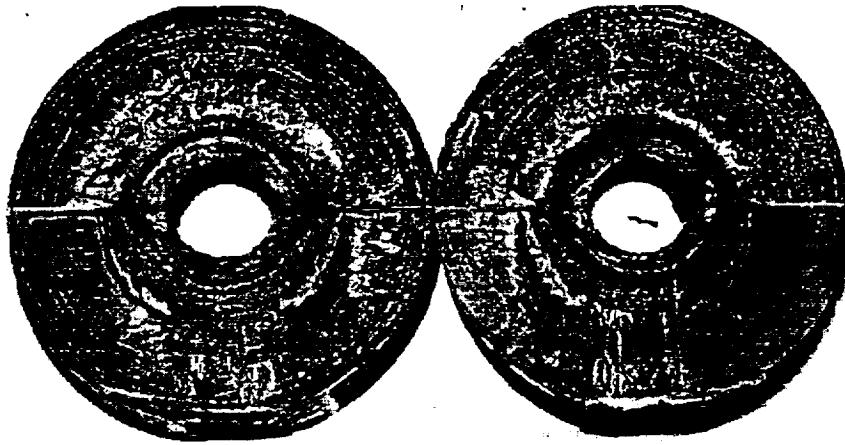


Figure 4: Typical Post Fire Bondline

4. RESULTS

The average of the four FPC motor post fire data is as follows:

Adhesive	Pre-Fire Blast Tube Dia. Mm/(in)	Char Depth Phenolic (Avg. Dia) mm/(in)	Char Depth Adhesive (Avg Dia) mm/(in)	Heat Affected Adhesive (Avg. Dia) mm/(in)
EA913NA	12.7 / (.5)	36 / (1.4)	51 / (2.01)	56 / (2.21)
EA946	12.7 / (.5)	36 / (1.4)	52 / (2.05)	57 / (2.24)
Tiga 321	12.7 / (.5)	36 / (1.4)	48.5 / (1.91)	51.5 / (2.01)
EC2615XLW	12.7 / (.5)	36 / (1.4)	49.5 / (1.95)	53 / (2.09)

Table 3: Post Fire Measurement

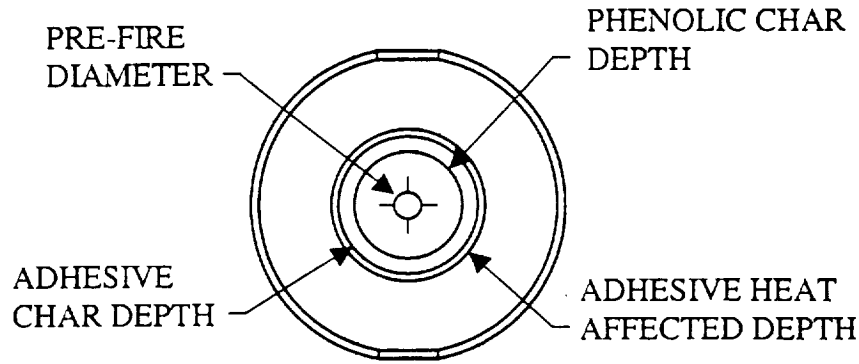


Figure 5: Typical Cross Section View

The intent of the thermocouples was to identify how fast the ablation of the adhesive occurred. The pressure transducers were used to plot the chamber pressure during the test see Figures 6 - 10. This data was used to identify the temperature and pressure during the ablation and to calculate an ablation rate. What the thermocouple data shows is that the first 2-5 mm (.100-.200 inch) of adhesive ablate very quickly (on the order of 1 second). Once the adhesive ablates into this region the ablation rate slows and seems to follow the char layer. The first thermocouples lost meaningful signal on the average of 1 second into the burn at an average pressure of 8.27 MPa (1200 psi). The second thermocouple in from the flame surface lost meaningful signal at an average of 15 seconds after ignition and 5.5 MPa. (800 psi) The ablation rate was calculated using the distance from the original flame surface to the second thermocouple divided by the time to reach the thermocouple-operating limit.

No anomalies were reported during the build, test or post fire inspection.

Adhesive	Average Ablation Rate mm/sec / (in/sec)
EA-946	.53 / (.021)
EA-913	.59 / (.023)
Tiga 321	.51 / (.020)
EC-2615XLW	.52 / (.021)

Table 4: Calculated Adhesive Ablation Rate

5. CONCLUSION

There are four conclusions that can be drawn from this testing. 1) The phenolic char depths on radial bond lines is approximately the same and vary depending on the position in the blast tube regardless of which adhesive was used. 2) The adhesive char depth of the candidate replacement adhesives is less than the char depth of the current adhesives. 3) The heat-affected depth of the candidate replacement adhesives is less than the heat-affected

depth of the current adhesives. 4) The ablation rates for both replacement adhesives are slower than that of the current adhesives.

The results of this testing indicate that the replacement adhesives perform as good or better than the current RSRM nozzle structural adhesives. A direct comparison of the candidate replacement adhesives shows that the RTG adhesive performs better under these thermal conditions than the 3M adhesive.

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FPC Motor Test
ETP-1541-001

P002 Chamber Pressure, Transducer: Taber 206, SL-39143

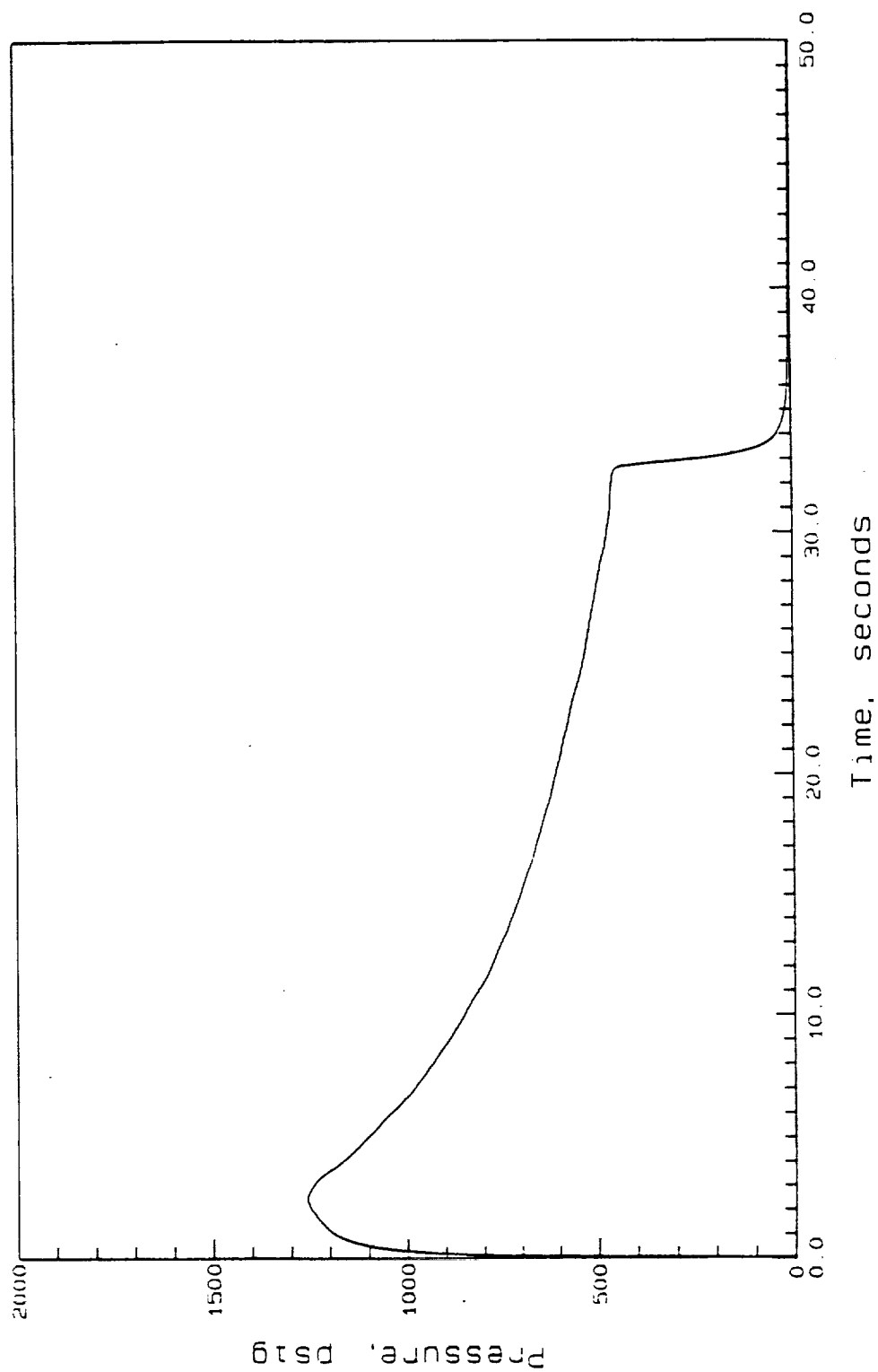


Figure 6: Typical Chamber Pressure Plot

FPC Motor Test
ETP-1541-001
TC13, Type K Thermocouple

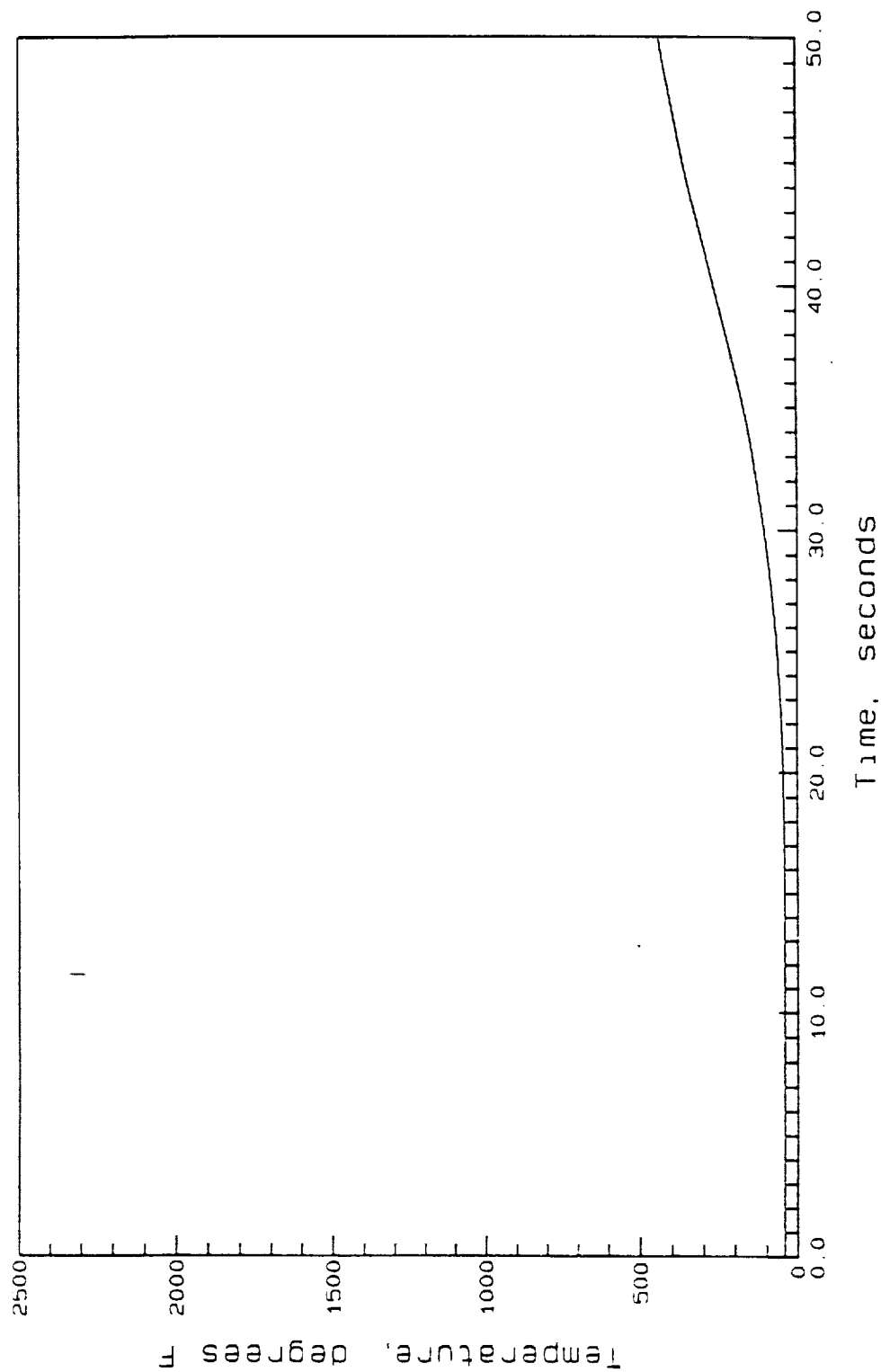


Figure 7: Typical Outer Thermocouple Plot

FPC Motor Test
ETP-1541-001
TC14, Type K Thermocouple

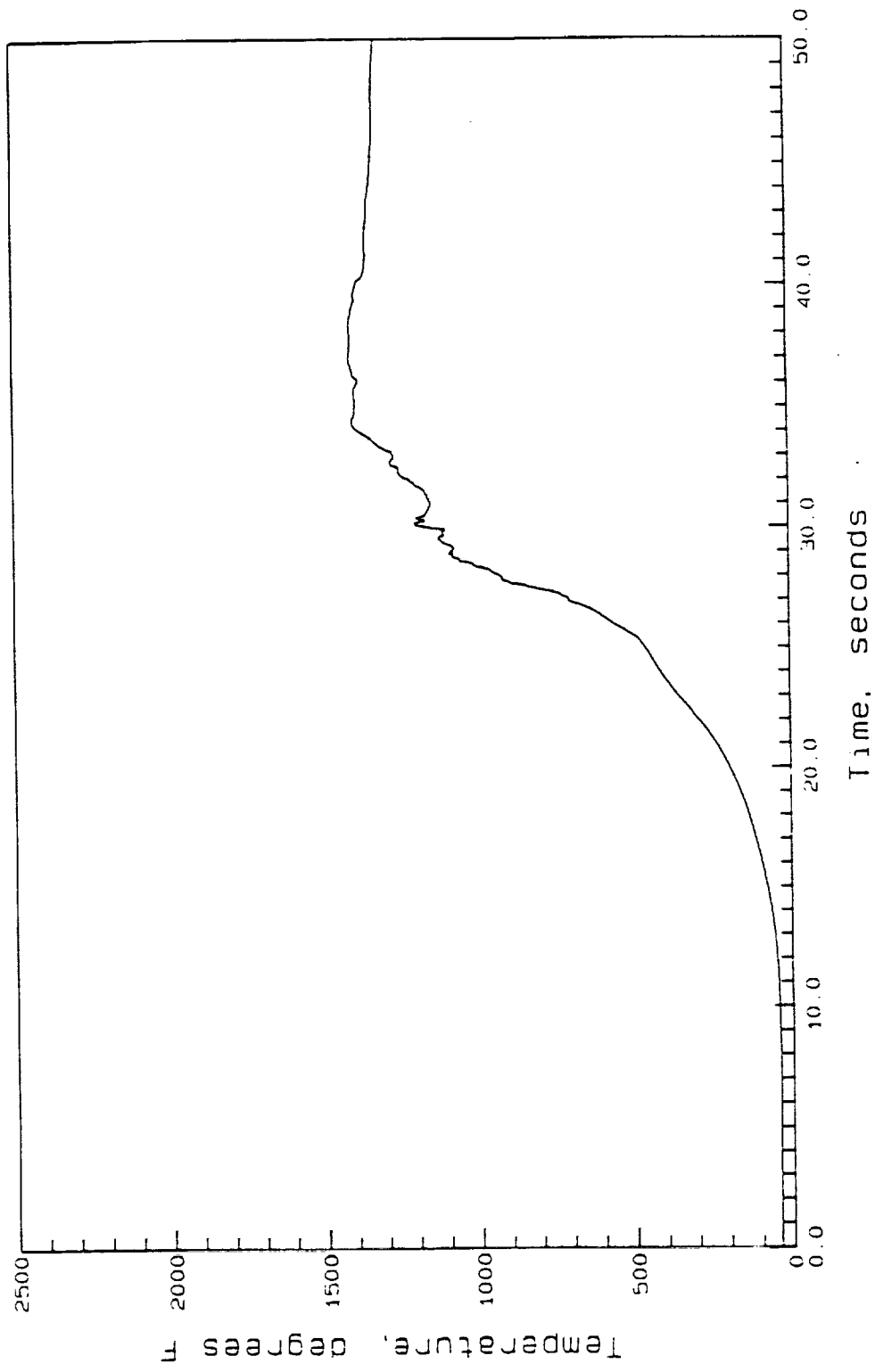


Figure 8: Typical Middle Outer Thermocouple Plot

FPC Motor Test
ETP-1541-001
TC15, Type K Thermocouple

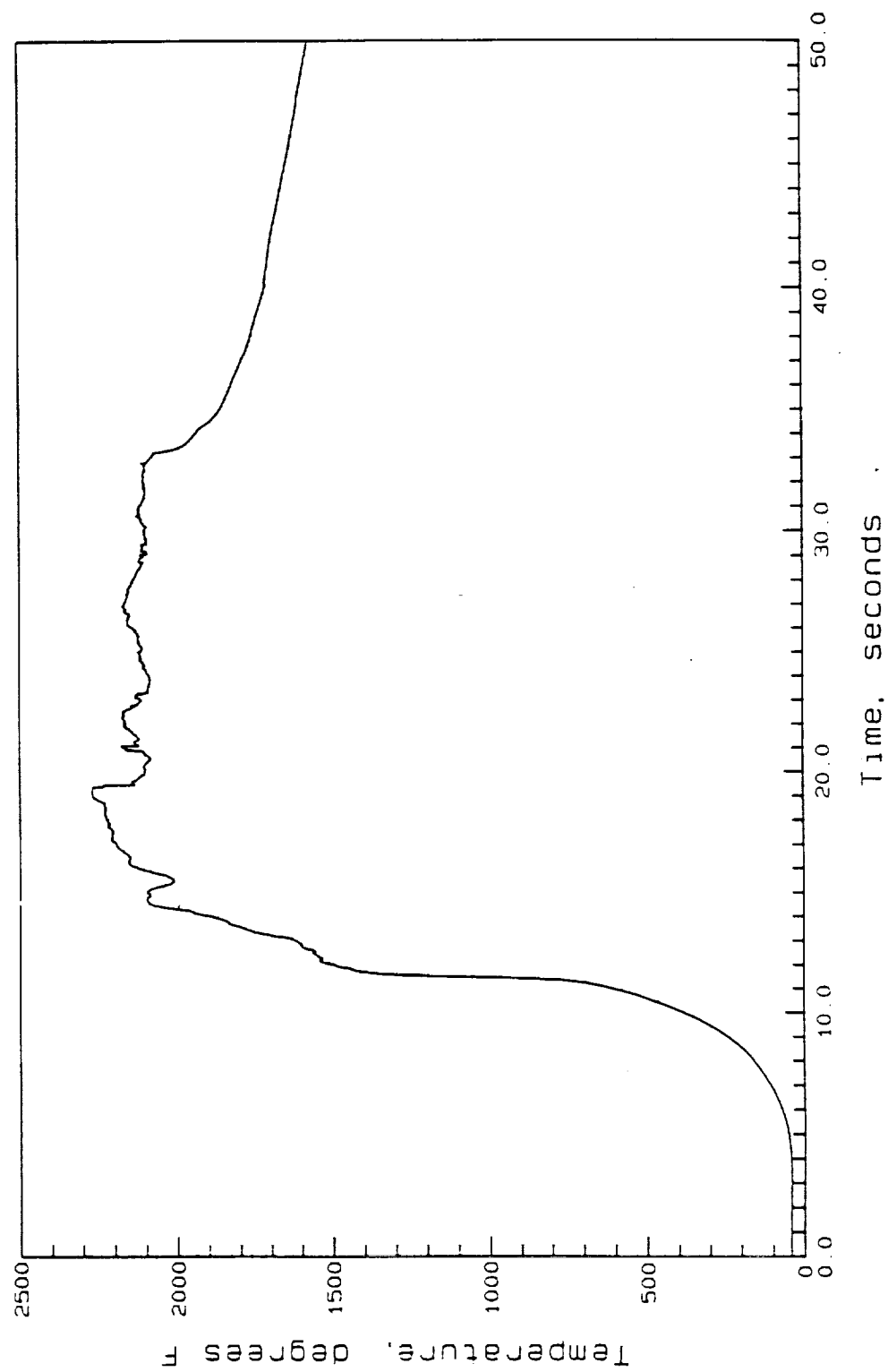


Figure 9: Typical Middle Inner Thermocouple Plot

FPC Motor Test
ETP-1541-001
TC16, Type K Thermocouple

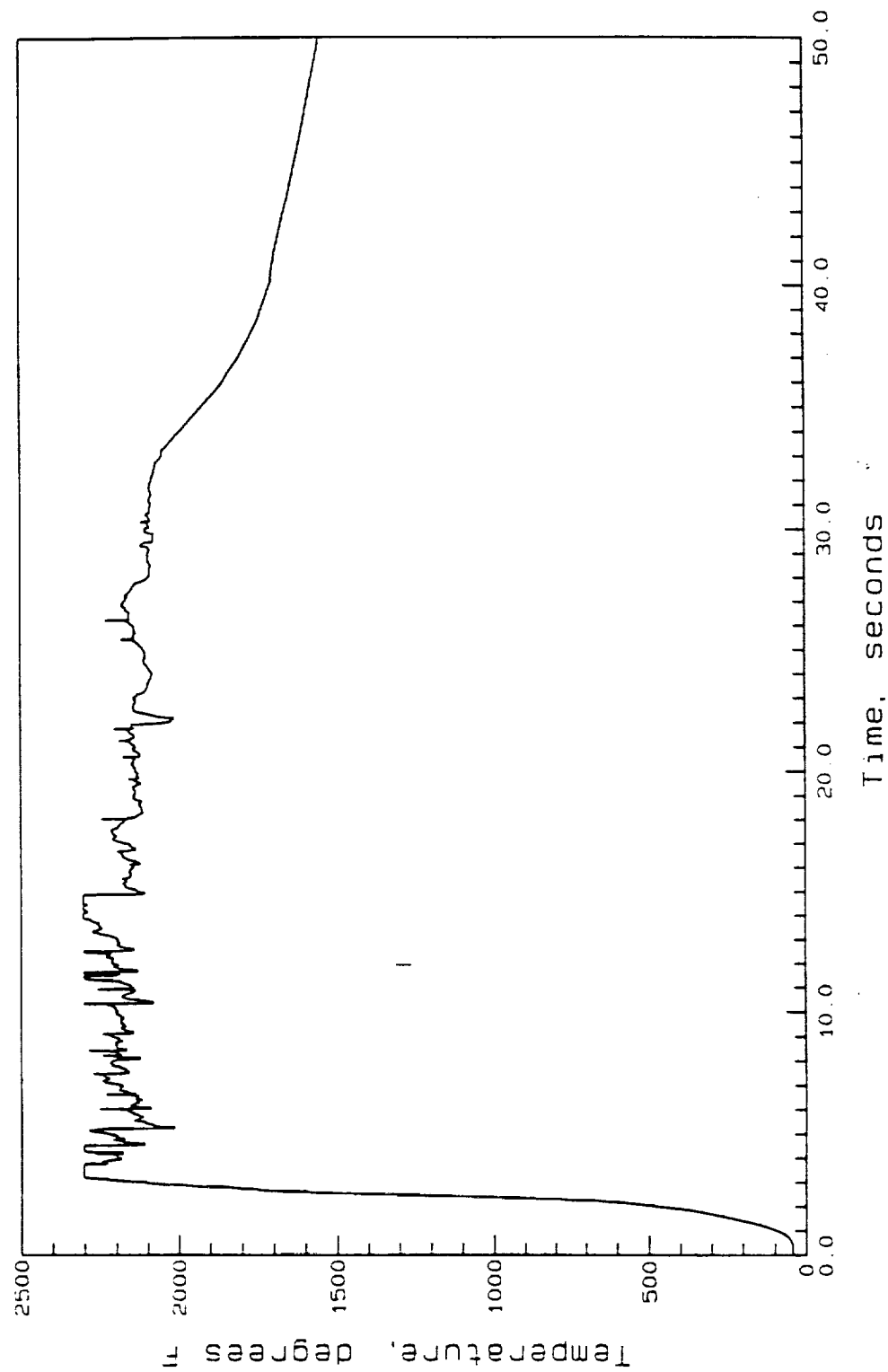


Figure 10: Typical Inner Thermocouple Plot